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**UNITED STATES LETTERS PATENT**

**FOR**

**HIGH DATA RATE BOREHOLE TELEMETRY SYSTEM**

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## **HIGH DATA RATE BOREHOLE TELEMETRY SYSTEM**

### **Cross-Reference to related Applications**

[0001] This application claims the benefit of U.S. Provisional Application No. 60/416,739, filed October 7, 2002.

### **5 Statement Regarding Federally Sponsored Research or development**

[0002] Not applicable

### **Field of the Invention**

10 [0003] This invention relates in general to downhole telemetry and, in particular to, the use of downhole signal repeaters for signal communication between surface equipment and downhole equipment.

### **BACKGROUND OF THE INVENTION**

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[0004] Without limiting the scope of the invention, its background is described in connection with transmitting downhole data to the surface during measurements while drilling (MWD), as an example. It should be noted that the principles of the present invention are applicable not only during drilling, but throughout the life of a wellbore including, but not limited to, during logging, testing, completing and producing a well. 20 The principles of the invention are also applicable to bi-directional communication between surface equipment and downhole equipment.

[0005] A variety of communication and transmission techniques have been attempted to provide real time data from the vicinity of the bit to the surface during drilling. The utilization of MWD with real time data transmission provides substantial benefits during a drilling operation. For example, continuous monitoring of downhole parameters such as weight-on-bit, torque, directional surveys, and formation parameters in real time provides for a more efficient drilling operations. In fact, faster penetration rates, better trip planning, reduced equipment failures, fewer delays for directional surveys, and the elimination of a need to interrupt drilling for abnormal pressure detection is achievable using MWD techniques.

10 [0006] At present, there are four major categories of telemetry systems that have been used in an attempt to provide real time data from the vicinity of the drill bit to the surface, namely mud pressure pulses, insulated conductors, acoustics and electromagnetic waves.

[0007] In a mud pressure pulse system, the resistance of mud flow through a drill string is modulated by means of a valve and control mechanism mounted in a special drill collar near the bit. This type of system generates a pressure pulse that travels up the mud column at or near the velocity of sound in the mud. It has been found, however, that the rate of transmission of measurements is relatively slow due to pulse spreading, modulation rate limitations, and other disruptive limitations such as the requirement of mud flow. Common mud pulse systems are limited to data rates of approximately ten bits per second, with normal transmission rates of 2-4 bits per second.

[0008] Insulated conductors, or hard wire connection from the bit to the surface, is an alternative method for establishing downhole communications. This type of system is

capable of a high data rate and two way communication is possible. It has been found, however, that this type of system requires a special drill pipe and special tool joint connectors which substantially increase the cost of a drilling operation. Also, these systems are prone to failure as a result of the abrasive conditions of the mud system and the wear caused by the rotation of the drill string.

[0009] Acoustic systems have provided a third alternative. Typically, an acoustic signal is generated near the bit and is transmitted through the drill pipe, mud column or the earth. It has been found, however, that the very low magnitude of the signal which can be generated downhole, along with the acoustic noise generated by the drilling system, makes signal detection difficult. Reflective and refractive interference resulting from changing diameters and thread makeup at the tool joints compounds the signal attenuation problem for drill pipe transmission.

[0010] The fourth technique used to telemeter downhole data to the surface uses the transmission of electromagnetic waves through the earth. It has been found, however, that in deep or noisy well applications, conventional electromagnetic systems are unable to generate a signal with sufficient magnitude to reach the surface.

[0011] In order to transmit higher data rates, repeaters have been proposed for both acoustic and electromagnetic systems. Installing in or connecting repeaters to the drill string have been described. See for example U.S. Patent 6,075,641 to Harrison, describing an electromagnetic repeater strapped to a drill string. These installations are highly susceptible to damage during drilling operations. Other devices, inserted in the

drill string, typically limit the open diameter of the drill string that is required to run wireline tools and other safety equipment.

[0012] Therefore, there is a demonstrated need for a high data rate, non-intrusive system that is capable of telemetering real time information in a deep or noisy well  
5 between surface equipment and downhole equipment.

### **SUMMARY OF THE INVENTION**

[0013] In one aspect the present invention contemplates a system for communicating  
10 information between downhole equipment in a wellbore and surface equipment. The invention comprises a first device disposed in a wellbore for receiving at least one first signal and transmitting at least one second signal. A surface device is used for receiving the at least one second signal and transmitting the at least one first signal. At least one repeater is disposed at a predetermined location in a wall of the wellbore for receiving  
15 and retransmitting the at least one first signal and the at least one second signal.

[0014] In another aspect, the invention contemplates a method for communicating information between downhole equipment in a wellbore and surface equipment, comprising; deploying a tubular member in the wellbore, the tubular member having a transmitter disposed therein; disposing at least one signal repeater at a predetermined  
20 location in a wall of the wellbore; and transmitting a signal from the transmitter to a surface receiver through the at least one repeater.

[0015] Examples of the more important features of the invention thus have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated.

- 5 There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

[0016] For detailed understanding of the present invention, references should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals, wherein:

**Figure 1** is a schematic drawing of a drilling system according to one embodiment of the present invention;

**Figure 2** is a block drawing of a repeater according to one embodiment of the present invention;

**Figure 3** is a schematic drawing of a section of a wellbore having multiple repeaters according to one embodiment of the present invention; and

**Figure 4** is a schematic drawing of a section of a well with a repeater being installed in a wall of the wellbore according to one embodiment of the present invention.

## DESCRIPTION OF PREFERRED EMBODIMENTS

[0017] Referring now to **FIG. 1**, a communication system including a signal generator and a plurality of signal repeaters for use with an offshore oil and gas drilling platform is schematically illustrated and generally designated **10**. A semi-submersible platform **12** is centered over a submerged oil and gas formation **14** located below sea floor **16**. A subsea conduit **18** extends from deck **20** of platform **12** to wellhead installation **22** including blowout preventers **24**. Platform **12** has a hoisting apparatus **26** and a derrick **28** for manipulating drill string **30**, positioned inside wellbore **32** during drilling operations. Drill string **30** maybe comprised of jointed tubing or alternatively may comprise coiled tubing. Wellbore **32** may be cased or uncased, depending upon the particular application, the depth of the well, and the strata through which the wellbore extends. In some applications, wellbore **32** will be partially cased, i.e., the casing will extend only partially down the length of wellbore **32**. While described for an offshore well, the system and methods described herein are equally suitable for land operations.

[0018] A bottom hole assembly (BHA) **80** is attached to the bottom of drill string **30**. BHA **80** comprises multiple tubular sections having a diameter commonly larger than the diameter of drill string **30**. Drill bit **100** is attached to the bottom of BHA **100** for disintegrating the formation **14**. A drilling fluid **40** is circulated from a surface pumping unit (not shown) through the drill string **30** and exits at the bit **100**. The drilling fluid **40** carries drilling cuttings back up the annulus between the drill string **30** and the wellbore **32** to a surface cleaning unit from which the drilling fluid is recirculated. A Measurement

While Drilling (MWD) system **52** with a plurality of sensors is disposed in BHA **80** for measuring various downhole parameters, including, but not limited to, formation evaluation parameters, directional survey parameters, and drilling parameters. The measured sensor data is transmitted by a signal transceiver **50** to surface transceiver **57** and the received signals are processed by surface system **55**. The processed signals may be used to improve the drilling process and evaluate the downhole formation. Both the downhole transceiver **50** and the surface transceiver **57** are adapted to transmit and receive signals for enabling bi-directional communication between the downhole and surface systems. Alternatively, separate devices may be used to transmit and to receive signals at each location, while still enabling bi-directional communication. The signals may be acoustic, electromagnetic (EM), and radio frequency (RF), or any other suitable transmission system suitable for telemetry of signals in a wellbore. Multiple transmission techniques may be enabled to provide backup communication capability.

**[0019]** Signal repeaters **60** are disposed in the wall of wellbore **32** to periodically boost the strength of the signals as they are attenuated during transit through the transmission medium. In one embodiment, repeaters **60** are installed while drilling or shortly after drilling wellbore **32**. Any number of such repeaters may be installed in the wall of wellbore **32**. The repeaters **60** are spaced such that the signals transmitted by transceiver **50**, while attenuated, still have sufficient magnitude to be readily received at least at the repeater **60** nearest the transmitter. Each repeater **60** (see **Fig. 2**) is self-contained and autonomous and comprises a receiver **110**, electronics module **120**, an energy source **140**, and a transmitter **130**. Receiver **110** and transmitter **130** may be

packaged as the same device, or , alternatively, may be packaged as separate devices.

Electronics module **120** comprises circuits **121** for conditioning the received signal and for powering the transmitter. In addition, electronics module **120** may contain a processor **122** having a memory **123** where processor **122** acts according to programmed

5 instructions stored in memory **123** for controlling the operation of the repeater **60**. Energy source **140** comprises batteries (not shown) which may be any batteries known in the art suitable for downhole use. Alternatively, the energy source may be a thermoelectric generator adapted to generate energy downhole based on the temperature gradients existing between the formation and the fluid **40** in wellbore **32**. Such generators are  
10 commercially available and will not be described further. In yet another preferred embodiment, a thermoelectric generator may be used to recharge suitable rechargeable batteries. Such a technique would extend the life of the repeater essentially indefinitely to enable use throughout the life of the well.

[0020] In one preferred embodiment, repeater **60** has at least one sensor **124**. Sensor  
15 **124** may be used to detect parameters of interest related to the surrounding formation and/or the fluid **40** in wellbore **32**. Such sensors may include pressure, temperature, and resistivity devices for detecting fluid pressure, fluid temperature and fluid resistivity of wellbore and/or formation fluids. Changes in such parameters over time may be related to formation production ability. Repeater **60** may also include sensors for determining the  
20 health of the repeater, such as for example, battery charge. The data from such sensors is included as an addition to the retransmitted signal.

[0021] In operation, in one embodiment, a signal **101** is received, processed, amplified, and retransmitted as signal **102** at a signal strength sufficient to reach the next repeater. Successive repeaters are likewise spaced at predetermined locations to be able to readily receive the signal transmitted by the previous repeater.

5 [0022] Spacing of repeaters may be determined by modeling the transmission characteristics of the formation and wellbore **32**. Alternatively, during the drilling operation, the transceiver **50** may periodically send a predetermined signal to the closest repeater which in turn sends a confirmation signal back to the downhole transceiver **50**. When the return message is no longer detectable at the transceiver **50**, the tool is raised in  
10 the hole until detection is reestablished and another repeater **60** is disposed in the wall of wellbore **32** using any of the techniques and devices described later. Multiple repeaters may be installed at each such location to provide redundant protection against repeater failure. Repeater **60** may be adapted to receive and transmit multiple types of signals, such as, for example, EM and acoustic signals. Repeater **60** may be programmed to  
15 change signal type when the received signal falls below a predetermined threshold. Alternatively, repeater **60** may be adapted to always transmit multiple types of signal to provide redundancy. Each repeater **60** may have a unique identifier and be considered as a node in a network transmission system. Commands for data may be directed along the network to a particular node. The command may be executed at the repeater node and a  
20 subsequent response sent back to the requester.

[0023] Repeater 60 may be adapted to operate at multiple frequencies to enable bi-directional communication, with downlink signals and uplink signals being at different frequencies, as shown in Fig. 3.

[0024] In one preferred embodiment, repeaters 60 are deployed into the wellbore 32 in a pocket 61 in an insertion sub 62 (see Fig. 3). The repeater 60 is adapted to penetrate the wall of wellbore 32 when propelled by an explosive charge 63 similar to that used in perforating charges known in the art.

[0025] In another preferred embodiment, see Fig. 4, repeater 460 is carried in cavity 465 in insertion sub 462 that is part of the bottomhole assembly and that is controlled by the bottomhole transceiver (not shown). Repeater 460 is inserted in the wall of wellbore 432 by the operation of telescoping piston 463. Insertion sub 462 contains a hydraulic system (not shown) for actuating the telescoping piston 463 on command from the transceiver. Insertion sub 462 may be directly connected electrically to the BHA transceiver (not shown). Alternatively, the insertion sub 462 may communicate with the transceiver (not shown) using any other communication scheme known in the art, including, but not limited to, acoustic and electromagnetic techniques.

[0026] After the initial drilling of the well, the well may be completed using equipment, such as intelligent completion equipment, adapted to use the existing repeaters. In addition, if required, additional repeaters may be installed in open hole sections of the well. Sensor data taken at repeater locations may be directed to the intelligent completion equipment for use in adaptively controlling well flow in a completed well. It should be noted that the principles of the present invention are

applicable not only during drilling, but throughout the life of a wellbore including, but not limited to, during logging, testing, completing and producing the well.

[0027] The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to  
5 one skilled in the art that many modifications and changes to the embodiment set forth above are possible without departing from the scope of the invention. It is intended that the following claims be interpreted to embrace all such modifications and changes.